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(54) **Title:** RELIABLE DETECTION OF A TRANSPORT FORMAT IDENTIFIER IN A TRANSPORT FORMAT IDENTIFICATION FIELD OF A DIGITAL COMMUNICATION SYSTEM

(57) **Abstract:** The application of soft, that is probability based, decision decoding to a format identifier field, in particular a transport format combination indicator (TFCI) field of a data signal in a noisy channel, in particular in digital data communication and 3G portable telephony. Soft decision decoding described includes various forms of block codes and also trellis codes.

RELIABLE DETECTION OF A TRANSPORT FORMAT IDENTIFIER IN A TRANSPORT FORMAT IDENTIFICATION FIELD OF A DIGITAL COMMUNICATION SYSTEM.

Field of the Invention

The present invention relates to error free detection of a format identifier in a data format identification field of a digital data communication and more particularly but not exclusively to detection of a Transport Format Combination Indicator (TFCI) within a TFCI field for use in 3G mobile telephony

Background of the Invention

In 3G communications systems, a Transport Format Combination Indicator (TFCI) is provided as a field in the datastream and is used to inform the receiver of the number of bits in each frame of the data for each of a number of types of communications services currently in use. As soon as the TFCI field is detected, the transport format combination, and hence the individual transport channels' transport formats, *i.e.* the number of code channels; the spreading factor and the puncturing/repetition rate, becomes available. Decoding of the transport channels then becomes possible. It follows that reliable detection of the TFCI field is essential and the TFCI field is thus protected by means of an error correcting code.

The ability of error correction to reconstruct distorted data is thus important in the context of TFCI, and the initial problem of data distortion in

noisy channels, such as communications channels, is important because of the general applicability of such channels to 3G communication.

The problem of communication channel related distortion has been much studied due to its importance in communication in general and there are numerous well-known approaches. The most direct way is the following:

The distortion is of a certain magnitude. The interference to a signal is determined by the relation of the power of the interference, to the power with which the signals were transmitted. The greater the ratio, the greater the resulting interference will be. The most direct way of minimizing the distortion is to reduce the ratio by increasing the power with which the signal is transmitted. The obvious problems with this approach are the increased cost incurred in sending a transmission at a higher power level and cases when a power increase is not possible due to capacity problems; for example with CDMA systems.

In order to provide better performance while maintaining the same transmitted power, several encoding methods have been devised which facilitate recovery of the distorted data. The data is encoded before transmission in such a way that following a limited distortion, the received data can be related only to a small group of possible candidate codewords. The transmitted codeword and therefore the data, can then be estimated by selecting from the group of candidate codewords the one that underwent the least amount of distortion.

Codes are typically a series of points on a graph. One important type of code that can be used is the Block code. In a Block code (see below) a series of points constitutes a vector which defines a codeword. Points are referred to by their graph coordinates. The power of the communication signal corresponds to the values of those coordinates.

A more commonly used code of the above-described type is the Trellis code. This is generally based on the binary convolutional code, meaning that it may consist of an infinite stream of bits. Unlike Block codes, a Trellis code sequence may consist of an infinite number of points. The popularity of the Trellis code is the result of Viterbi's discovery that, a basic structure is common to all Trellis codes and that they may all be described using a Trellis diagram. Thus, a general optimal decoder exists for all possible Trellis codes. As a result, a generic optimal Trellis decoder has been mass-produced in the form of a small piece of hardware easily installed in an existing decoding apparatus. This affords Trellis codes a large degree of universality. Block codes on the other hand, do not have a general optimal decoder based on their block structure. Thus, they have not been widely used. Additionally, these codes have been viewed as requiring very complex algorithms for their soft-decision decoding.

Block codes consist of sequences, or blocks, of points. Each sequence constitutes a vector, and each vector corresponds to a given codeword. Presently, a few methods of decoding exist. For Block codes, maximum likelihood decoding exists in two ways:

One method takes the entire received word and, using a table of all legitimate codewords, tries to match the received word with the legitimate codeword it resembles most. This is done because we assume that it is most likely that the least amount of distortion occurred. Therefore we look to find the codeword which represents that word which would have to have undergone the least amount of distortion in order to have been transformed into the received word. We do this by taking the points received (corresponding to the transmitted codeword) and measure the metric of the distance between them and each of the legitimate codewords. For AWGN (additive white Gaussian noise) channels, the metric is measured by taking the Square Euclidean Distance (SED) between the points of the received word and the points of a legitimate codeword. This method is optimal since (a) the codewords in these codes are selected by virtue of their distance from each other, and (b) this method factors in the sum of the distance of all the points in the codeword. This method, however, is not very useful because of the high number of operations (computations) necessary to find the codeword with the smallest SED between it and the received word.

The other existing method is to construct a Trellis diagram for the Block code and then decode it by using Viterbi decoding. Although this method is optimal (i.e. it produces the same results as the first method of maximum likelihood decoding), Viterbi decoding is not always efficient in terms of decoding complexity.

In addition to the optimal decoding methods mentioned above, certain sub-optimal decoding methods exist for Block codes. However, even these methods frequently require a large number of operations for complex codes. There is thus a widely recognized need for an efficient decoding method for block codes, including the so-called Reed Muller codes.

In 3G systems, an information stream of bits is encoded to offer transport services over the radio transmission link. The channel coding scheme is a combination of error detection, error correction, rate matching, interleaving and transport channel mapping onto the physical radio channels. The Transport Format Combination Indicator is a set of bits used to inform the receiver of the number of bits in each frame for each of the services currently in use. As soon as the TFCI field is detected, the transport format combination, and hence the individual transport channels' transport formats; *i.e.* the number of code channels; the spreading factor and the puncturing/repetition rate, may be revealed. Decoding of the transport channels then becomes possible, as mentioned above. Reliable detection of the TFCI field is thus essential, and therefore it is protected by means of an error correcting code. Further details on the above is available by consultation with the following documents, the contents of which are hereby incorporated by reference:

O. Amrani and Y. Be'ery, "Reed-Muller codes: projections onto GF(4) and multilevel construction," accepted for publication *IEEE Trans. Inform. Theory,* 2000.

3GPP Technical specification group, Multiplexing and channel coding (FDD), TS25.212, December 1999.

Block codes and the like use minimum Euclidean distance and other like metrics to calculate a most probable codeword. They are thus referred to as soft decoding algorithms, as distinct from hard-decision decoding algorithms which employ the Hamming distance measure.

Summary of the Invention

According to a first aspect of the present invention there is provided the application of a code supporting soft decision decoding to a format identifier field of a data signal in a noisy channel.

Preferably, the format identifier field is a Transport Format Combination Indicator (TFCI) field.

Preferably, the application is for use with 3G mobile telephony.

Preferably, the soft decision decoding is trellis decoding.

In an alternative embodiment, the soft decision making utilizes block codes.

The application preferably comprises the step of constructing the field into a (30,10) code as a punctured version of a code whose construction is based on the union of 16 cosets of the Reed-Muller RM(1,5) code.

The application preferably comprises performing soft decision decoding of the RM(1,5) code based on the projection of its codewords onto a code over GF(4).

The application alternatively comprises performing soft decision decoding of the (30,10) code based on the projection of its codewords onto a code over GF(4).

The application alternatively comprises performing soft decision decoding of the RM(1,4) code based on the projection of its codewords onto a code over GF(4).

Preferably, the noisy channel is a two-way communication channel.

According to a second aspect of the present invention there is provided apparatus for receiving a two-way data communication, the apparatus comprising a control field decoder for decoding a format identifier field of the communication, the decoder being operable to use soft decoding to decode said field.

Preferred embodiments use either or both of trellis and block decoding methods.

The soft decoding is preferably operable to make maximum likelihood calculations to discriminate between more and less probable correct codewords, and thereby correcting an incorrect word.

The decoder is preferably operable to decode the TCFI field from a (30,10) code represented as a punctured version of a code whose construction is based on the union of 16 cosets of the Reed-Muller RM(1,5) code.

The decoder is alternatively operable to perform soft decision decoding of the RM(1,5) code based on the projection of its codewords onto a code over GF(4).

The decoder is alternatively operable to perform soft decision decoding of the (30,10) code based on the projection of respective codewords onto a code over GF(4).

The decoder is alternatively operable to perform soft decision decoding of the RM(1,4) code based on the projection of the respective codewords onto a code over GF(4).

Apparatus according to the present invention is suitable for incorporation within 3G mobile telephony equipment.

According to a third aspect of the present invention there is provided a method of two-way digital communication comprising using a multiplicity of data formats suitable for different types of data on a unified data system using a control field to signal the format,

the method comprising encoding the control field using a scheme suitable for soft decoding at a receiver, and decoding accordingly at a receiver.

Preferably, the control field is a Transport Format Combination Indicator (TFCI) field.

The method preferably comprises the step of constructing the control field into a (30,10) code as a punctured version of a code whose construction is based on the union of 16 cosets of the Reed-Muller RM(1,5) code.

The method preferably comprises performing soft decision decoding of the RM(1,5) code based on the projection of its codewords onto a code over GF(4).

The method alternatively comprises performing soft decision decoding of the (30,10) code based on the projection of its respective codewords onto a code over GF(4).

The method alternatively comprises performing soft decision decoding of the RM(1,4) code based on the projection of its codewords onto a code over GF(4).

The method is suitable for use with 3G mobile telephony equipment.

Brief Description of the Drawings

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings, in which:

Fig. 1 is a simplified diagram which shows the encoding and decoding sides of a communication link in a 3G telephony link to which the present invention may be applied, and

Fig. 2 is a simplified depiction of the application of a code supporting soft decision decoding to a format identifier field of a data signal in a noisy channel, according to one embodiment of the present invention.

Description of the Preferred Embodiments

Reference is now made to Fig. 1, which is a simplified diagram which shows the encoding and decoding sides of a communication link in a 3G telephony link to which the present invention may be applied.

In Fig. 1, information, that is to say the data intended to be communicated, and control bits together 10 are prepared to enable the preparation of a data unit such as a data packet for transmission through a noisy channel in a 3G wireless telephony system. The 3G wireless telephony system is intended to support numerous types of data including voice and all types of multimedia. Thus no assumptions are possible about an arriving data packet and only if the control bits are intact is it possible for the receiver to know how to decode the packet. It is thus essential that the control bits are encoded in a manner in which they can be safely and reliably decoded at all levels of distortion likely to be encountered in the channel.

The data and control bits 10 are thus preferably encoded using a channel coder 20. The channel coder 20 preferably uses turbo encoding TC, convolutional encoding CC, block encoding BC, or any other encoding technique. Mapping and interleaving is then carried out using a mapping and interleaving unit 30. The mapping amounts to grouping the coded bits for selecting a modulation signal from the constellation used. High-level modulation, i.e. constellation sizes, are required in order to increase the gross bit rate. Interleaving is a method for mitigating the channel impairments, such as fading or noise bursts, by means of spreading the coded sequences in time.

The data is then passed to a channel modulator 40 where it is modulated onto a suitable carrier for transmission over the channel. Over the channel the data is likely to be distorted so that the signal picked up by the receiver is not identical to the signal transmitted.

At the receiving end, the received signal is demodulated at a demodulator 50. It is then demapped and de-interleaved at demapper and de-interleaver 60, and, following this, it is decoded using any one of a number of soft decoding techniques at a decoder 70. The decoding technique used is one that is compatible with the code used at encoder 20, and will be described in more detail below.

According to embodiments of the present invention, soft decoding is used for reliable detection of the TFCI field. Soft decoding differs from hard decoding in that it is more powerful. Because it utilizes probabilities based on accumulative received data it is able to identify and correct errors that are well beyond the scope of hard decoding.

In one preferred embodiment of the present invention, block codes are employed for encoding the TFCI bits. The block codes that are used are the first order Reed-Muller code RM(1,4) and a (30,10) code. Figure 1, as discussed above, depicts a digital communication system employing the above codes and the decoder of the current invention. The TFCI bits are considered as control bits. The channel encoders employ either convolutional (CC) or turbo codes (TC) for the information and some of the control bits. The TFCI bits are

encoded by using the block codes (BC) described above. The obtained coded bit streams are then interleaved and mapped to the slots of the radio frame.

A. The construction of the code

The number of TFCI bits is variable, up to 10 bits, and is set at the beginning of a call via higher layer signaling. For improved detection reliability the TFCI bits are encoded using a (30,10) punctured sub-code of the second order Reed-Muller code, RM(2,5)=(32,16,8). The coding procedure is depicted in Figure 2.

(The specific mapping of the TFCI bits to the slots of a radio frame has no effect on the current invention and therefore is not discussed here.) The code words of the (32,10) code are the linear combinations of 10 basis sequences:

- the all 1's sequence (row 1 of Eq. (1))
- five OVSF sequences (rows 2-6 of Eq. (1))
- four of the so called *mask sequences*:

Mask 1	00101000011000111111000001110111
Mask 2	00000001110011010110110111000111
Mask 3	00001010111110010001101100101011
Mask 4	00011100001101110010111101010001

A preferred embodiment of the present invention decodes the (32,10) code by using a coset-decoding approach. This code can be constructed as the union of 16 cosets whose coset leaders are the 16 linear combinations of the four Mask sequences. Thus, all the cosets are shifted versions (shifted by the coset leader) of a particular subcode. The subcode is generated by taking all the linear combinations of the six basis vectors comprising the all 1's and the 5 OVSF (Orthogonal Variable Spreading Factor) sequences. It turns out that this subcode is actually the first order Reed-Muller code RM(1,5) whose generator matrix is given in (1)

$$G_{RM(1,5)} = \begin{bmatrix} 11111111111111111111111111111111 \\ 01010101010101010101010101010101 \\ 00110011001100110011001100110011 \\ 00001111000011110000111100001111 \\ 00000000111111110000000011111111 \\ 00000000000000001111111111111111 \end{bmatrix}. \tag{1}$$

The RM(1,5) has a certain construction [AB] that can be employed to obtain a low complexity decoding method. According to the [AB] construction each codeword is arranged in a 4x8 array, where each column corresponds to 4 consecutive bits of the original codeword. The first column holds the first four bits of the codeword, the second column holds the next 4 bits and so on. A column of 4 bits has either an even Hamming weight (type even), or an odd Hamming weight (type odd), according to the number of non-zero elements in the respective column. Each column has a unique image, also called a *projection*, over GF(4). Conversely, each GF(4) symbol has four 4-bit representations, two even and two odd. The two representations of the same type are complementary to each other (*e.g.* for the symbol $1 \in GF(4)$, the two

complementary odd representations are 0100 and 1011). We define the *projection of the array* as the vector over GF(4) obtained by taking the 8 individual projections of the columns. Using the above notations, the Reed-Muller RM(1,5) code can be defined as follows:

Definition 1. Construction of RM(1,5): *The RM(1,5) is the set of all the binary 4x8 arrays that satisfy the following conditions:*

1. *The Hamming weight of each and every column is even.*
2. *The projection of the array is a codeword of the [8,1,8] repetition code over GF(4).*
3. *The top row is a codeword of the binary [8,4,4] code RM(1,3).*

B. The decoding algorithms

Based on Definition 1, a multilevel construction of the RM(1,5) code is obtained and consequently decoding can be performed as follows (Fig. 3):

Decoding Algorithm 1 (for RM(1,5)):

Assume that a codeword is transmitted over a noisy channel, and that the corresponding received sequence of channel measurements is arranged in a 4x8 array.

1. For each of the 8 columns of the array, compute the *metric* of each of the four GF(4) symbols (using the two even representations). Note that the metric is a predetermined reliability measure (*e.g.* for the additive white Gaussian noise channel, the metric may be taken as the Squared Euclidean Distance between a binary representation of the GF(4) symbol

and the received 4 channel measurements). There are two complementary even representations for each GF(4) symbol, choose the better one (called the *preferred representation).*

2. For each of the four codewords of the [8,1,8] code over GF(4) construct a binary 4x8 array using the preferred representation for each GF(4) symbol. Then, perform the following steps:

2.1. Check the top row of the binary array, if it is a codeword of the RM(1,3)=[8,4,4] code, then proceed to step 3, otherwise

2.2. Perform soft or hard-decision decoding to obtain a [8,4,4] codeword. (Note that inverting the bit in position j of the top row corresponds to choosing the complementary representation for the j's column.)

3. Compute the overall metric for each of the four obtained arrays.

4. Among the four codewords obtained in Step 3, choose the one with the minimum metric.

Decoding algorithm 1 can now be easily employed for decoding the (32,10) code (or its punctured version) based on the coset decomposition described in Subsection A (Fig. 4):

Decoding Algorithm 2 (for the (32,10) TFCI code):

1. For each of 16 cosets whose coset leaders are the linear combinations of the Mask sequences, obtain a candidate codeword by employing decoding Algorithm 1.

2. Among the 16 codewords thus obtained choose the one with the minimum metric as the output of the decoder.

Note that the decoding of the (32,10) code, or its (30,10) punctured version, amounts to the same basic operation. The difference is that in the punctured version, the metric of the coordinates corresponding to punctured bits should be taken as zero. Thus, any of the above decoding algorithms can be employed for decoding the (30,10) code.

C. Coding and decoding in the Split mode

3G defines another mode of operation, the so-called *Split mode*, where only 5 TFCI bits are encoded using a (16,5) biorthogonal block code. This is actually the Reed-Muller code RM(1,4) which can be defined, as in the case of the RM(1,5) code, by arranging the codewords in a two dimensional array, as follows [AB]:

Definition 2. Construction of RM(1,4): *The RM(1,4) is the set of all the binary 4x4 arrays that satisfy the following conditions:*

1. *The Hamming weight of each and every column is even.*
2. *The projection of the array is a codeword of the [4,1,4] repetition code over GF(4).*
3. *The parity of the top row is even.*

Based on the construction described in Definition 2 the following decoder is used in a particularly preferred embodiment of the present invention. (Fig. 5):

Decoding Algorithm 3 (for RM(1,4)):

Assume that the received sequence is arranged in a 4x4 array.

1. For each of the 4 columns of the array, compute the metric of each of the four GF(4) symbols (using the two even representations). There are two complementary even representations for each GF(4) symbol, choose the better one.

2. For each of the four codewords of the [4,1,4] repetition code over GF(4) construct a binary 4x4 array using the preferred representations for each of the symbols. Then, perform the following steps:

2.1. If the parity of the top row is even, then proceed to Step 3, otherwise

2.2. Complement the representation of the column having the least amount of impact on the overall metric.

3. Compute the overall metric for each of the four obtained arrays.

Among the four codewords obtained in Step 3, choose the one with the minimum metric as the output of the decoder.

There is thus provided a method and apparatus for providing reliable decoding of the TFCI field using a number of soft decoding methods. The use of soft decoding according to the above-described embodiments is preferable in that the decoding is able to take account of maximum likelihood estimation in order to arrive at a most probable correction.

It will be appreciated that the methods of decoding may be implemented equally well in software and in hardware.

It is appreciated that features described only in respect of one or some of the embodiments are applicable to other embodiments and that for reasons of space it is not possible to detail all possible combinations. Nevertheless, the scope of the above description extends to all reasonable combinations of the above described features.

The present invention is not limited by the above-described embodiments, which are given by way of example only. Rather the invention is defined by the appended claims.

Claims

We claim:

1. The application of a code supporting soft decision decoding to a format identifier field of a data signal in a noisy channel.

2. The application according to claim 1, wherein the format identifier field is a Transport Format Combination Indicator (TFCI) field.

3. The application according to claim 1, used with 3G mobile telephony.

4. The application according to claim 1 wherein the soft decision decoding is trellis decoding.

5. The application according to claim 1, wherein the soft decision making utilizes block codes.

6. The application according to claim 1, comprising the step of constructing the field into a (30,10) code as a punctured version of a code whose construction is based on the union of 16 cosets of the Reed-Muller RM(1,5) code.

7. The application according to claim 6, comprising performing soft decision decoding of the RM(1,5) code based on the projection of its codewords onto a code over GF(4).

8. The application according to claim 6, comprising performing soft decision decoding of the (30,10) code based on the projection of its codewords onto a code over GF(4).

9. The application according to claim 1, comprising performing soft decision decoding of the RM(1,4) code based on the projection of its codewords onto a code over GF(4).

10. The application according to claim 1, wherein the noisy channel is a two-way communication channel.

11. Apparatus for receiving a two-way data communication, the apparatus comprising a control field decoder for decoding a format identifier field of the communication, the decoder being operable to use soft decoding to decode said field.

12. Apparatus according to claim 11, the soft decoding comprising block decoding.

13. Apparatus according to claim 11, the soft decoding comprising trellis decoding methods.

14. Apparatus according to claim 11, the soft decoding being operable to make maximum likelihood calculations to discriminate between more and less probable correct codewords, and thereby correcting an incorrect word.

15. Apparatus according to claim 11, the decoder being operable to decode the TCFI field from a (30,10) code represented as a punctured version of a code whose construction is based on the union of 16 cosets of the Reed-Muller RM(1,5) code.

16. Apparatus according to claim 11, the decoder being operable to perform soft decision decoding of the RM(1,5) code based on the projection of its codewords onto a code over GF(4).

17. Apparatus according to claim 11, the decoder being operable to perform soft decision decoding of the (30,10) code based on the projection of respective codewords onto a code over GF(4).

18. Apparatus according to claim 11, the decoder being operable to perform soft decision decoding of the RM(1,4) code based on the projection of the respective codewords onto a code over GF(4).

19. Apparatus according to claim 11, incorporated within 3G mobile telephony equipment.

20. Apparatus according to claim 14, incorporated within 3G mobile telephony equipment.

21. A method of two-way digital communication comprising using a multiplicity of data formats suitable for different types of data on a unified data system using a control field to signal the format,

the method comprising encoding the control field using a scheme suitable for soft decoding at a receiver, and decoding accordingly at a receiver.

22. A method according to claim 21, wherein the control field is a Transport Format Combination Indicator (TFCI) field.

23. A method according to claim 21, comprising the step of constructing the control field into a (30,10) code as a punctured version of a code whose construction is based on the union of 16 cosets of the Reed-Muller RM(1,5) code.

24. A method according to claim 23, comprising performing soft decision decoding of the RM(1,5) code based on the projection of its codewords onto a code over GF(4).

25. A method according to claim 23, comprising performing soft decision decoding of the (30,10) code based on the projection of its respective codewords onto a code over GF(4).

26. A method according to claim 23, comprising performing soft decision decoding of the RM(1,4) code based on the projection of its codewords onto a code over GF(4).

27. A method according to claim 21, used with 3G mobile telephony equipment.

28. A method according to claim 22, used with 3G mobile telephony equipment.

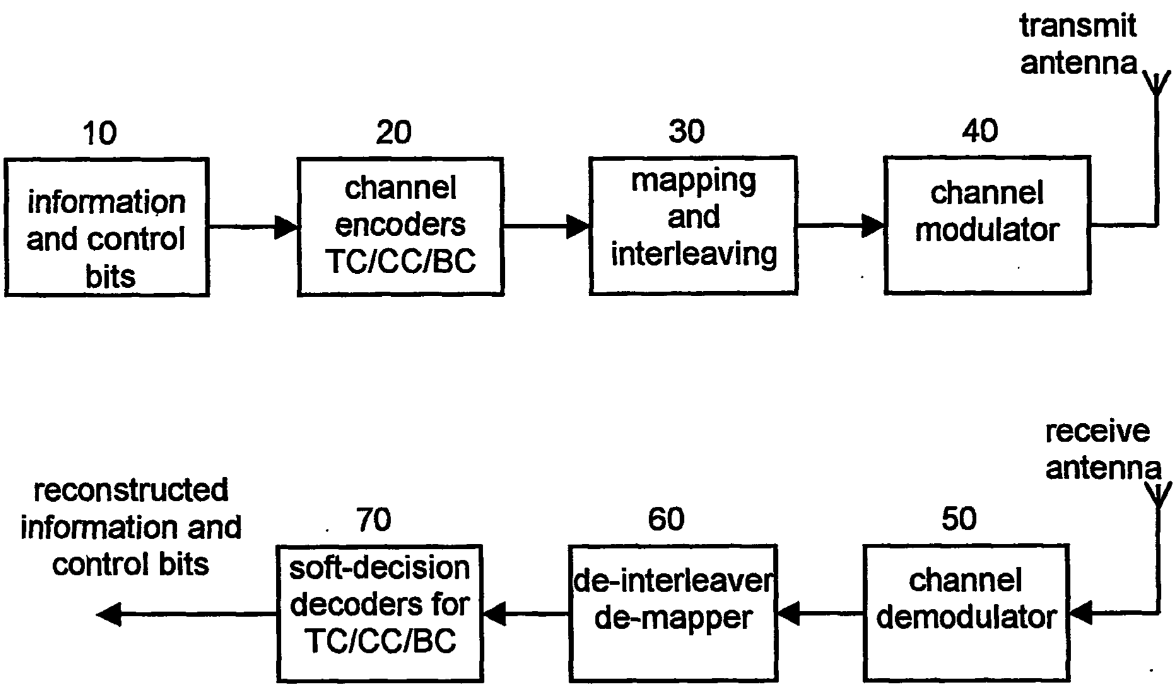
transmit antenna
10
information and control bits
20
channel encoders TC/CC/BC
30
mapping and interleaving
40
channel modulator
receive antenna
reconstructed information and control bits
70
soft-decision decoders for TC/CC/BC
60
de-interleaver de-mapper
50
channel demodulator

Fig. 1

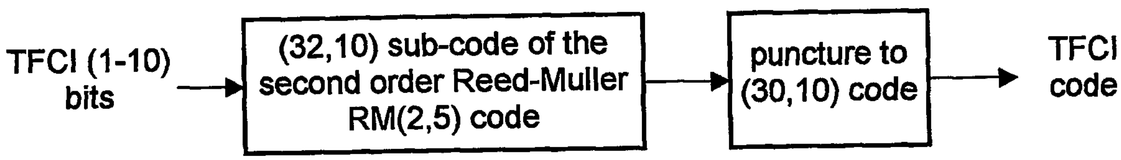
TFCI (1-10)
bits
(32,10) sub-code of the
second order Reed-Muller
RM(2,5) code
puncture to
(30,10) code
TFCI
code

Fig. 2